perspective paper

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The Challenge of Ecosystems and Biodiversity: A Perspective Paper

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Introduction

Does investment in global ecosystem protection warrant its costs? This is the vital question Salman Hussain and colleagues address in their challenge paper (Hussain et al. 2012). The paper focuses on examining the costs and benefits of three global policies: investing in increasing agricultural productivity, extending protected areas, and reducing deforestation. The assessment meticulously evaluates the three policy options, focusing especially on estimating their anticipated benefits. They are first measured in bio-physical units as improvements from the baseline (business as usual, BAU) land cover and habitat condition (mean species abundance, MSA). BAU is projected until 2050 under a set of future economic, demographic, and environmental conditions developed at the OECD. Ecological benefit estimates are then monetized using meta-analyzed ecosystem valuation results from a large number of primary studies from around the globe. Cost estimates are adopted from unrelated assessments, which examine roughly similar policy options to the ones evaluated in the challenge paper.

Benefits from ecosystem protection typically are highly heterogeneous spatially. The challenge paper addresses this by separately examining three different biomes—temperate forests and woodlands, tropical forests, and grasslands. Added spatial resolution is obtained from grid-cell level benefit estimations. Regional level summaries highlight global heterogeneity and also help understand the incidence of ecosystem degradation in the absence of added protections.

Summing up the estimated benefits and costs of the three global policy options examined, the authors find that investing in increasing agricultural productivity and reducing deforestation have substantial net benefit potential. The estimated benefit-cost ratios depend heavily on the assumptions and fall between roughly 3 and 30 for reduced deforestation and between about 3 and 20 for agricultural productivity investments. So according to the challenge paper, every dollar invested in reduced deforestation has the potential to return $3 to $30 worth of benefits, while agricultural productivity investments could return roughly $3 to $20 per each dollar put in.[1] Extending protected areas appears considerably less attractive. It barely reaches and often remains below the break-even point, with estimated benefit-cost ratios ranging between 0.2 and 1.4.

Brief Assessment

Projecting environmental change far into the future in response to a large scale policy intervention, let alone economically valuing it, is rife with difficulties and uncertainties. For example, despite considerable methodological progress over the last few decades, economic valuation of environmental quality remains imperfect even when studying values in one particular location and under a set of known environmental conditions. Here, we need to draw results from primary valuation studies from many different countries, ecological systems, policy settings, and economic conditions to forecast future economic benefits outside the contexts of the original studies. Reflecting these and other uncertainties, the authors usefully consider a broad range of assumptions to determine reasonable upper and lower bounds for the benefit estimates. The challenge paper also makes a noteworthy contribution by conducting meta-analytic regressions to improve the transfer of the primary valuation results to a new setting. Regardless, huge methodological and empirical difficulties remain at the outset. This is not to criticize the challenge paper—it would be tremendously difficult to formulate alternative approaches to provide equally or more robust results—but to help evaluate its findings. Given these difficulties and uncertainties, the benefit-cost estimates in the challenge paper are probably best viewed as qualitative indicators comprising some quantitatively helpful information.

Regardless, the results are instructive. Developing roughly consistent assessments across different policy options, the challenge paper discovers that two of the policy options, agricultural productivity investments and reduced deforestation, are promising from economic standpoint whereas the third option, increased protected areas, has difficulty satisfying minimum economic criteria. This is extremely helpful information for ranking and more thoroughly evaluating the policy options examined.

More generally, the results from the challenge paper highlight several important aspects of ecosystem protection. First, investing in ecosystem protection can have substantial economic potential. Even though the economic importance of the ecosystems and their protection is now widely acknowledged

[1] Agriculture is one of the main threats to biodiversity so the net benefits from improved agricultural productivity probably should be scaled down due to the adverse ecological effects from agricultural intensification.

and increasingly well understood, this basic finding derived from a meticulous and geographically broad assessment is powerful and informative. Second, not all potential investments in ecosystem protection pass the benefit-cost test. Therefore, thorough vetting of different policy alternatives is critically important to identify the best options for implementation. Third, estimating the benefits and costs of ecosystem protection is exceedingly feasible, though it involves substantial challenges and uncertainties. Because of the very nature of ecosystem protection, its benefits are often not transacted through markets so are difficult to accurately pinpoint. Moreover, complicated and poorly understood ecological processes and human-nature interactions underlie the production of ecosystem services, further complicating their valuation. Investing in research and data to better understand ecosystem services and their economic value may therefore be highly beneficial.

Before I go deeper into discussing a few complementary perspectives, it is important to commend the assessment by Hussain and colleagues. Albeit facing an especially difficult task, the authors are able to compile rigorous and systematic assessments of the benefits and costs of three important and often debated policy options. The assessment also acknowledges and discusses some of the chief caveats and presents the main estimates as a range to reflect uncertainties. Moreover, the assessment arrives at meaningful and conceivable results. The research puzzle in the assessment involves so many challenging pieces that constructing a logical assessment at global scale, which Hussain et al (2012) presents, is exceedingly difficult.

I will next set aside the inescapable restrictions of the challenge paper. Environmental valuation is now so broadly conducted and methodologically assessed that it suffices to note that substantial difficulties and uncertainties remain in any assessment, especially in the context of long time horizons and a global geographic scale. Certainly, one might tweak some of the estimates, assumptions, and methodological approaches in the challenge paper, but doing so would unlikely dramatically alter the key results, such as the ranking of policy alternatives or overall benefit-cost judgments. Given the task at hand, the challenge paper provides an adequately rigorous, thorough, and critical assessment to help experts form informed opinions on whether investments in ecosystem protection are sensible in the context of many other demands for spending.

Perspective Paper Overview

The rest of this perspective paper discusses two complementary areas. The first area of discussion, coastal and marine ecosystems, highlights these vast and globally essential ecosystems, which are outside the scope of the challenge paper, but include some of the most productive and threatened ecosystems worldwide. The second area of discussion, designing international forest conservation policies, recommends systematically targeting these policies to produce multiple benefits (avoided emissions, biodiversity). This likely will generate greater overall net gains than feasible by focusing solely on avoided emissions.

Coastal and marine ecosystems

Coastal and marine ecosystems serve a wide range of ecological functions and provide people with many economically valuable products and services (Barbier et al. 2008, 2011, Spalding et al. 2010, Schipper et al. 2009). The importance of coastal and marine ecosystems is heightened by the concentration of human populations near coasts. It is estimated that over half of the world's population lives within 120 miles (about 200 km) or closer from the coast, with some regions, such as Latin America and the Caribbean, where the percentage of coastal populations is substantially higher (Hinrichsen 1998; Lemay 1999).

Status

Despite their ecological and economic importance, many coastal and marine ecosystems are degraded and their area has been substantially reduced (e.g., FAO 2007a; Spalding et al. 2010). Coastal ecosystems are particularly vulnerable and they are considered among the most threatened and rapidly disappearing natural environments worldwide (Valiela et al. 2001). Even the recent increase in protected areas has not stemmed the gradual degradation and disappearance of coastal ecosystems worldwide (Lotze et al. 2007; Halpern et al. 2008; Spalding et al. 2010; Siikamäki et al. 2012).

Some of the ecologically most essential and economically valuable coastal ecosystems, such as mangroves, continue to experience exceedingly high loss rates, which in many areas are multiple times the global rate of tropical deforestation. For example, mangroves in the Americas have lost about 40% of their range about three decades ago (Valiela et al. 2001).

Coral reefs comprise yet another example of important but threatened ecosystems. Coral reefs are biodiversity hotspots, which feed economic benefits to fisheries, tourism, and other sectors. For example, the coral reef system alongside the Caribbean coasts of Mexico, Belize, Guatemala, and Honduras—the second largest reef system worldwide—provides habitat for an estimated over 10,000 species and plays a critical role in the broader regional environment. But coral reefs are also exceedingly vulnerable to damage by coastal development, sedimentation and other pollution, water acidification, fishing activities, and several other threats related to human activities. In the Caribbean, coral reefs have already lost almost one third of their historical range and it is estimated that another 20% or so will be lost in the absence of additional conservation measures in the next few decades (Sherman and Hempel 2009). Moreover, the remaining corals are frequently degraded, with one study finding that the hard coral on reefs has been reduced from around 50% to 10% cover in the last three decades (Gardner et al. 2003).

Fisheries

Coastal and marine ecosystems provide a broad range of economically important ecosystem services. I will not try to cover their full range here but instead highlight their economic importance by focusing on fisheries. Fisheries depend on coastal and marine habitats and provide an important source of food, employment, and income worldwide. Fish accounts for around 15% of global population's intake of animal protein and over half of this fish protein originates from capture fisheries (FAO 2010). Fisheries also generate considerable commercial activity, ranging from large commercial operations catering international exports to small-scale and artisanal fisheries along the coasts throughout the world. Coastal populations, especially small-scale fishers, often heavily depend on fisheries for income and food, which also makes them susceptible to any adverse developments regarding available fish catch, such as fisheries stock collapses or otherwise reduced catches.

Coastal and marine fisheries throughout much of the world have developed according to roughly similar trends. Despite increases in fishing capacity, capture fisheries production has plateaued or is already declining (FAO 2008). Global production peaked in 1996 and has since then slightly declined and considerably fluctuated.

While about three decades ago, roughly 10% of the world's fish stocks were overexploited or depleted, today about one third of them fall under this category (FAO 2010). The proportion of underexploited or moderately exploited stocks has reduced from around 40% from the mid-1970s to 15% in 2008. When overexploited, harvests reduce the future productive potential of the fisheries and subject it to a potential collapse. Harvests in fully exploited fisheries, which currently comprise about half of world's fish stocks, match the maximum sustainable production of the stock, without room to increase production or buffer to allow for unexpected environmental conditions, such as relatively frequent but poorly understood weather patterns (for example, El Niño/La Niña).

Problems in the governance and management of world's fisheries substantially reduce the economic contribution of the fish harvest sector. The magnitude of these losses is hard to estimate, but a recent assessment puts them at roughly $50 billion annually (World Bank 2009). According to the same assessment, the cumulative losses due to unsustainable fisheries management in 1974-2008 amounted to over $2 trillion. By improving the governance of fisheries, a portion of the lost economic benefits due to unsustainable management could be recovered.

Several factors have contributed to this natural resource management failure, including: (i) inappropriate economic incentives and subsidies that encourage overcapacity; (ii) high and growing demand for limited resources; (iii) poverty and lack of alternatives in coastal communities; (iv) fisheries' complexities, lack of knowledge, and the associated uncertainties; (v) lack of governance; (vi) interactions of the fishery sector with other sectors and their environmental impacts; and (vii) stock fluctuations due to natural causes (Swan and Greboval 2004, Salas et al. 2011).

What is the cost of improved fisheries management? While this is perhaps yet harder to estimate than the value of lost opportunities, it is safe to suggest that for many fisheries and in many parts of the world, even relatively moderate investments in improved governance and management of fisheries could potentially generate considerable benefits, even assuming fairly high costs of designing and implementing fisheries reforms. Simple solutions may not be available, however, and it is likely that the most cost-effective approaches involve a combination of interventions, such as improving fisheries property and management rights, adapting economically more efficient and sustainable governance systems (for example, catch-share systems), removing perverse subsidies encouraging overfishing and overcapacity, and improving systems for fisheries science, planning and monitoring. Focusing on just the few policy interventions with the greatest potential, such as fisheries governance reform and improved information systems, probably could help recover significant amounts of the estimated $50 billion annual losses due to unsustainable management.

Designing international forest conservation policies

One of the policy options examined in the challenge paper involves a program to reduce emissions from deforestation and degradation (REDD). My purpose next is to illustrate that benefits from REDD programs will crucially depend on what objective, carbon or biodiversity, they address. I argue that while carbon-focused REDD programs will benefit biodiversity; it is possible to configure these programs to achieve considerably greater biodiversity benefits without a loss of emission reductions. The cost of a more biodiversity focused REDD program will be greater, but jointly targeting biodiversity and GHG mitigation should be more cost-effective than addressing only one goal.

Considering both climate change and the loss of biodiversity in the context of REDD is also motivated by international agreements and political commitments declared at high-level international gatherings, including Kyoto, Rio de Janeiro, Copenhagen, Cancun, Nagoya, and more. These efforts have resulted in two separate international conventions, the United Nations Framework Convention for Climate Change (UNFCCC) and the Convention for Biological Diversity (CBD), both signed at the Earth Summit in Rio de Janeiro in 1992. The limited achievements as well as the many challenges faced by the UNFCCC are perhaps more widely known, although the CBD is equally or even more ambitious in its goals, seeking to halt biodiversity loss in the near term. However, it is widely acknowledged that the CBD has been unable to substantially slow the rate of biodiversity loss, so improvements are needed (*Convention on Biological Diversity* 2010).

REDD programs

REDD programs have received considerable attention for their potential to provide low-cost options to mitigate global GHG emissions by engaging developing countries in some form of international climate policy architecture (Angelsen 2008; Kindermann *et al*. 2008b; Sohngen 2009). Rather than adopting high-cost mitigation actions domestically, developed countries could finance developing countries to achieve similar but less costly emission reductions through reduced deforestation. REDD programs also have the potential to provide emission reductions in the near future, which is particularly important to achieving near-term emission reduction targets with politically acceptable economic costs.

More fundamentally to climate policy, reducing deforestation is central because it is among the chief contributors to global greenhouse gas (GHG) emissions and a particularly pressing problem in the developing world (IPCC 2007, Gibbs *et al*. 2007; Angelsen 2008). According to the most recent estimates, average annual emissions of carbon dioxide from deforestation and forest degradation are roughly 1.2 Gt of carbon, or about 4.4 Gt of carbon dioxide, which represents about 12% of total anthropogenic carbon emissions (van der Werf *et al*. 2009). Using another reference point, the estimated current annual emissions from deforestation are roughly equal to the emissions from all sources in the entire European Union in 2009 (UNFCCC 2011). Moreover, deforestation has the potential to be yet more detrimental if efforts to stem forest losses are not successful. World's forests store more carbon in biomass and soils than currently resides in the atmosphere (IPCC 2007; Pan *et al*. 2011). Much of this carbon pool is not covered by existing reduction targets or management frameworks.

From the perspective of biodiversity conservation, stemming deforestation is critical, because habitat loss is one of the main drivers of biodiversity loss, and the conversion of forests to agricultural uses is among the most detrimental kinds of land use change in its effects on biodiversity (Pereira *et al*. 2010). The conversion of natural areas to agricultural, residential, and commercial uses reduces the habitat available to support species and populations. As natural habitats continue to disappear, the ranges of many species shrink and become fragmented. Both phenomena reduce species richness and abundance and eventually drive species to extinction when the remaining habitats are unable to support minimum viable populations.

Spatial variation of biodiversity losses and carbon dioxide emissions from deforestation

While any habitat protection will produce some benefits to biodiversity, biodiversity is highly spatially heterogeneous. When REDD focuses on avoiding carbon emissions, biodiversity will benefit in locations where REDD has the greatest economic potential to reduce emissions. As demonstrated below, these areas are generally not where the greatest biodiversity benefit potential exists. The geographic differences between the most attractive target areas of carbon and biodiversity-focused programs are relatively stark.

To help highlight the tradeoffs between biodiversity and avoided emissions, Figure 1a-f shows global maps of above ground forest carbon, mammal species richness, endemic species richness, and potential agricultural revenue, deforestation rate, and estimated cost of avoided emissions due to deforestation. These maps are drawn from a high resolution (five minute resolution, about 9 km by 9 km grid cells) global dataset compiled by Siikamäki and Newbold (2012). Forest carbon (Fig. 1a) denotes the mass of above-ground carbon in the forest biomass (metric tons per hectare), as estimated by Kindermann *et al*. (2008a). Biodiversity measures (Fig 1b-c) are compiled using global digitalized maps of species ranges from the IUCN (2010) and information on endemic species from Olson *et al*. (2001). Annual potential agricultural revenues (Fig 1d) indicate the opportunity cost of conservation, as estimated using data from Naidoo and Iwamura (2007). Deforestation rates (Fig 1e) are estimated by ecoregion (Olsen et al. 2001) using data from the FAO Forest Resource Assessment (FRA 2005). The cost of avoided emissions (Fig 1f) is estimated by ecoregion using data on the opportunity cost of land and total annual emissions.

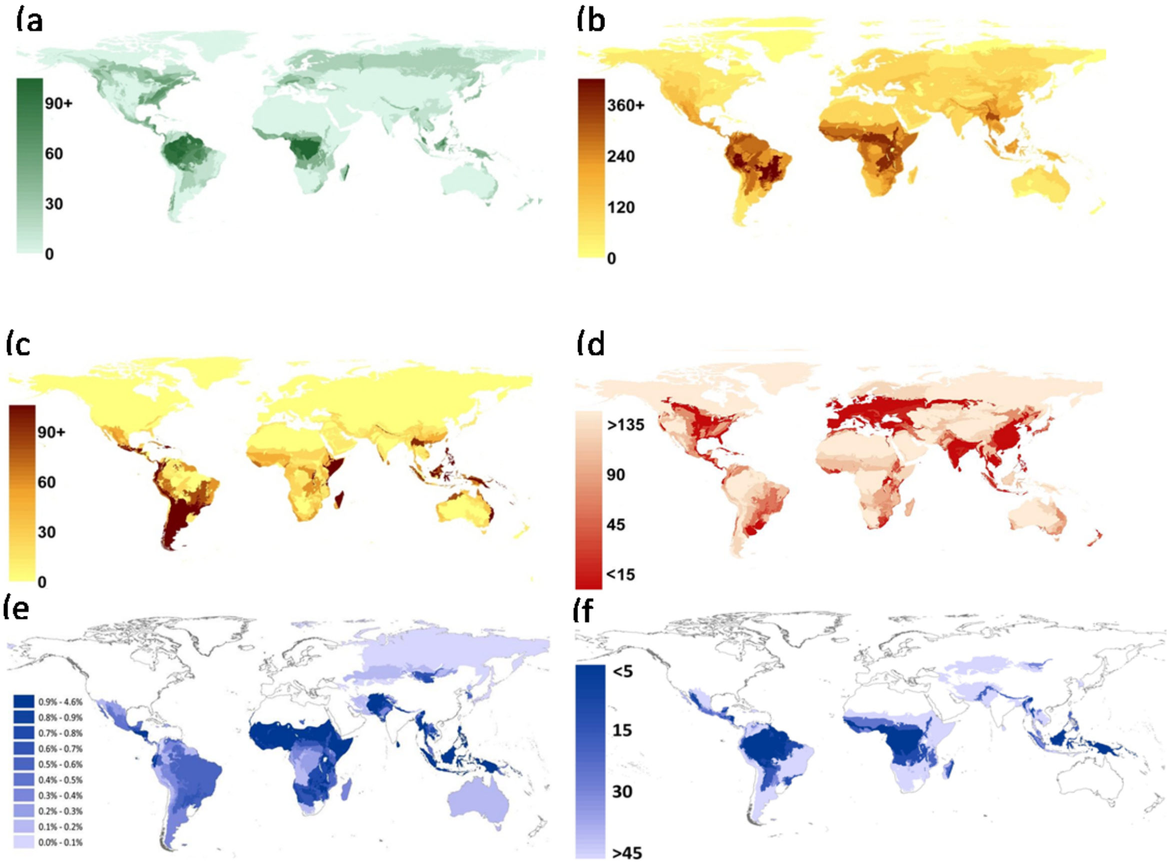

Figure 1. Global maps of above ground carbon, mammal species richness, endemic species richness, potential agricultural revenue, deforestation rate, and opportunity cost of avoided emissions. **a.** Tons of carbon ha^{-1}, on average per ecoregion. **b.** Total number of mammal species per ecoregion. **c**. Total number of endemic mammal, bird, amphibian, and reptile species per ecoregion. **d.** Potential agricultural revenue, USD ha^{-1}, on average per ecoregion. **e.** Deforestation rate, on average per ecoregion, annually. **f.** Estimated cost per ton of avoided emissions from deforestation, on average by ecoregion. (Compiled using data from Siikamäki and Newbold 2012).

The geographic distribution of species richness (Fig 1b) is markedly different from the amount of forest carbon (Fig 1a). Forest carbon is relatively high in the Amazon region, Central Africa, and Indonesia, Malaysia, and Papua New Guinea, while species richness is highest in northeast Columbia, Ecuador, Eastern Africa, coastal regions in Southeast Asia, and in mountain ranges around Mongolia and Tibet. Endemic species (Fig 1c) show similar patterns but are even more divergent from forest carbon, with several endemic species hotspots such as the southern South American continent situated in areas relatively low in forest carbon.

Figure 1e shows that the highest rates of deforestation occur in parts of Indonesia, Papua New Guinea, and several other parts of Southeast Asia. Several regions in South America, especially the Amazonas, parts of Bolivia, and Nicaragua, also have relatively high rates of deforestation. Central Africa, which is particularly rich in forest carbon, has a relatively low rate of deforestation.

The economically most attractive areas for REDD are shown in darkest color in Fig 1.f, which shows where the cost per ton of avoided emissions is lowest. Here, I focus only on non-Annex I countries, which are the prime targets of REDD. Overall, Fig 1f indicates that the Amazonas, much of the broader Central African region, and parts of Southeast Asia will be the most attractive to REDD programs that would focus on generating net revenue from carbon credits most cost effectively.

Effectiveness of carbon-focused REDD in promoting biodiversity

Spatial correlations between the key variables that will influence the attractiveness of a region for REDD programs and biodiversity conservation are relatively weak. Although species richness tends to be high in areas both rich in carbon and subject to high deforestation, Siikamäki and Newbold (2012) find practically zero correlation between the opportunity cost per ton of emissions avoided (a key measure influencing the attractiveness of REDD investments) and species richness. This suggest that if REDD programs are targeted to deliver carbon emission reductions at the least possible cost then these programs may not deliver particularly high biodiversity benefits. In fact, REDD programs that focus exclusively on carbon may not be more effective at protecting biodiversity than programs that randomly select forest parcels for protection.

Figure 2. Geographic targeting alternative forest conservation programs (ecoregions selected for conservation). a. Program to generate REDD credits at the least cost per ton carbon. b. Program to support species richness at the least cost per species (from Siikamäki and Newbold 2012).

The ecoregions targeted by two alternative forest conservation programs, carbon and species programs, confirm the above observation (Fig 2). The first program mimics a REDD-type policy focused on maximizing forest carbon emission reductions under a budget constraint. The second program is focused on biodiversity conservation and aims to maximize the number of endemic species protected under a budget constraint. For the available budget, these programs both consider spending about one fifth of the estimated foregone agricultural net revenue from the total elimination of all deforestation in all non-Annex I countries. This budget is intended to illustrate the potential scope of the large scale international policy proposals in the context of REDD, such as the proposals presented and rejected in the United States Congress in 2008-2009.

The carbon-focused program (Fig 2a) concentrates in the Amazonas, Central Africa, Indonesia and Papua New Guinea, the species-focused program distributes conservation investments much more broadly, including a large number of ecoregions distributed across the world. The species program (Fig 2b) targets areas differently from the carbon program, and thereby delivers more biodiversity benefits. But as a consequence, the species program also would generate less avoided carbon emissions. In the above example, the reduction in the carbon emissions from the species program is about 44% of that from the carbon program. On the other hand, the species program protects nearly six times the number of endemic species as does the carbon program.

Discussion

What are the implications of the above complementary perspectives in the context of the challenge paper and global biodiversity conservation more generally? First, expanding the scope beyond terrestrial systems is warranted. Coastal and marine ecosystems are rich in species, ecologically and economically essential, and face threats which are similar or greater in magnitude as threats in the terrestrial systems. Moreover, significant and potentially highly cost-effective policy options may be available in coastal and marine systems. However, pinpointing the most cost-effective options and their benefit-cost ratios requires further assessments. Improved fisheries management seems particularly attractive, because it could help protect biodiversity while also improving the economic productivity of world's fisheries. Second, forest conservation policies have multiple benefits, such as avoided CO_2 emissions and biodiversity, so these policies should be designed and evaluated from the perspective of multiple objectives. This helps generate greater overall benefits per dollar invested in conservations. While the magnitude of potential gains from improved design is an empirical matter, the analysis discussed above suggests that REDD programs could produce substantially greater overall benefits if biodiversity and avoided emissions are considered joint objectives. A related point is that improved spatial targeting of conservation interventions in general can substantially increase their cost-effectiveness. Often, a small sub-set of all location candidates produce a vast majority of total potential benefits. A key challenge is to identify the most advantageous locations to be targeted for conservation.

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